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OPTIMISED HEAT TREATMENT DURING WIRE AND SPRING MANUFACTURE

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ABSTRACT

Current research reveals that the heat treatment of wire and the heat treatment to harden wire and to temper springs must be taken in conjunction with each other in order to improve strength and shaping properties of oil-hardened spring steel wire. An experimental hardening and tempering plant developed at Ilmenau University of Technology in the laboratory of the “Wire and Spring” research group has been used to carry out experiments on many variations of all heat treatment parameters. This paper is a survey of the experiments using certain of the results as an example of how it will be possible to make stronger springs in future if the wire and spring industry cooperate, also thereby consuming less energy.

Index terms - spring steel wire, helical compression spring, heat treatment, hardening, tempering

1. INTRODUCTION

Helical compression springs are today used in many applications. There has been a steady increase in the demands made of them, however, over recent years, for instance by the automotive industry. One demand is that they should weigh less and less and another that they should take up less and less space. Both demands can be met only by increasing the capacity for energy storage of the spring and its strength. The reserves for any improvements are to be found in the heat treatment.

The last few years have seen the “Wire and Spring“ research group at Ilmenau TU cooperating with wire and spring manufacturers in various studies on the hardening and heat treatment of wire [1-4]. These studies have shown that the manufacture of helical compression springs with high dynamic and thermal capacity is only possible if the material properties are exactly known and can be influenced precisely.

2. DEMANDS ON THE SPRING STEEL WIRE

Dimensioning of springs is carried out according to (1) with reference to the permitted torsional stress. A spring made of wire with a high yield point under torsional stress $\tau_{\mathrm{t\,zul}}$ is therefore stronger and will thus be capable of storing more energy, which would be a means of saving material and installation space.

$$\tau_{\mathrm{vorh}} = \frac{8 \cdot D \cdot F}{\pi \cdot d^3} \leq \tau_{\mathrm{t\,zul}} \qquad (1)$$

At present, a testing station developed by the “Wire and Spring” research group is the only way there is of determining the yield point under torsional stress $\tau_{\mathrm{t\,zul}}$. This means that for industrial dimensioning purposes, the yield point under torsional stress $\tau_{\mathrm{t\,zul}}$ is computed from the tensile strength R_m depending on the type of spring and manufacturing technology in use. For example, DIN EN 13906 assigns the value 0.56 to the factor $\tau_{\mathrm{t\,zul}}/R_m$ for presetted helical compression springs. The yield point under torsional stress $\tau_{\mathrm{t\,zul}}$ must be optimised in order to increase the strength of a helical compression spring. The measuring instruments available make it possible to determine the $\tau_{t\,zul}/R_m$ relationship directly for various types of heat treatment process used in wire and spring manufacture. It has been possible to prove that there is no fixed relationship between the nominal strength values in tensile testing (yield point $R_{p0,2}$ and tensile strength R_m) and the values in torsion testing (yield point under torsional stress $\tau_{t0,04}$ as $\tau_{t\,zul}$ and maximum torsional strength τ_{tmax}). The relationship between these two sets of values is fundamentally dependent on the wire material, but is then considerably influenced by how the wire is heat-treated and the spring is heat-treated (Fig. 1 to 3).

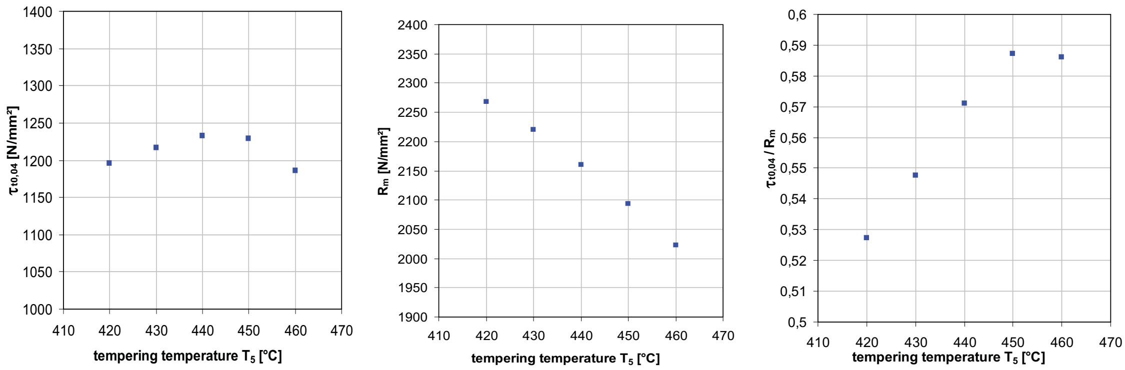


Fig. 1 to 3: *Diagrams for $\tau_{t0,04}$; R_m **and the ratio** $\tau_{t0,04}/R_m$ above the tempering temperature T_5 of wire production. The wire samples were austenitized and spring-tempered in each case with identical parameters.*

When spring steel wire is ordered, this is done according to the tensile strength, with reference to DIN EN 10270-2. The result at the works is then that wire which has been hardened and tempered by different wire manufacturers with the same tensile strength R_m but in different hardening and tempering equipment or hardening and tempering procedures can be very varied in its yield point under torsional stress $\tau_{t\,zul}$. When the wire is used to make springs, these variations result in springs which vary in their capacity and may thus mean that a component fails early.

3. TEMPERING OF STEEL SPRING WIRE AND SPRINGS

First, here is a diagram of the tempering processes in wire and spring manufacture (Fig. 4). Only taking these processes consistently in conjunction to each other will lead to an improvement of the strength and shaping properties [2]. A large number of investigations of tempering procedures were therefore made as a first step, to find out how they influence the strength and shaping properties of the wire material. It was not possible to employ the passage tempering used in industry for these experiments because to do so would have involved a disproportionate quantity of material and length of time. A further reason is that these types of plant would also be unsuitable to full and independent examination of all parameter variants in all tempering stages, working as they do with wire tempering sequences and interdependent periods of time (the periods depend on one another because of the plant construction) spent by the product in the separate parts of the process, i.e. austenitizing furnace, oil bath, lead bath, water bath. This led the group to develop the experimental hardening and tempering plant shown in Fig. 6 for the process stages of passage tempering which are shown in Fig. 5. With this equipment it is possible to work through a huge variation of treatment parameters with small quantities of wire using short lengths of 1m.

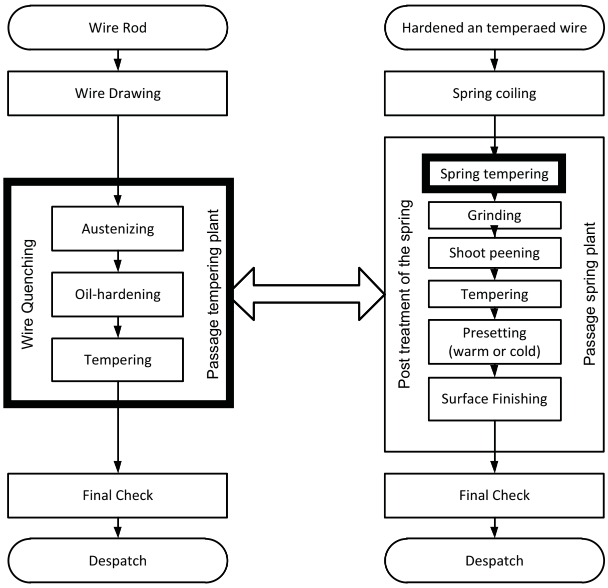


Figure 4*: Manufacturing process chain for steel spring wire and cold-shaped helical compression springs made from it*

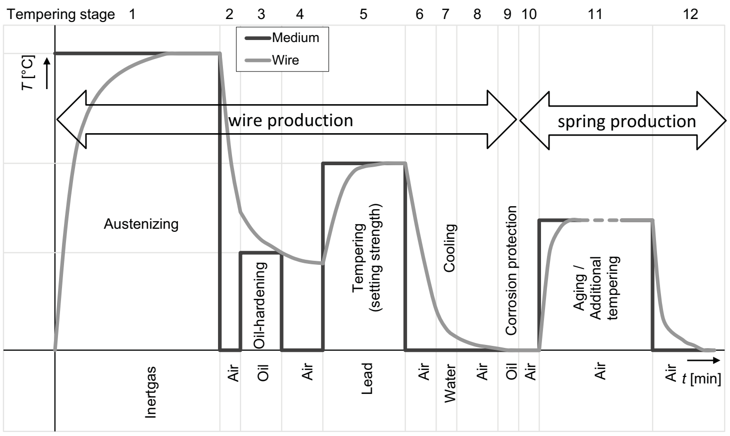


Figure 5*: Qualitative diagram of the stages of the hardening process and the tempering of the spring or component [1]*

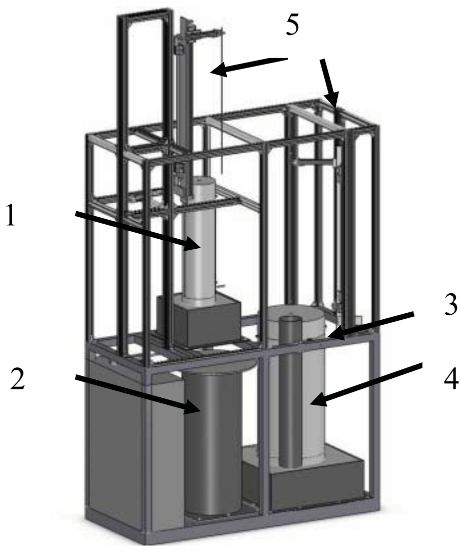


Figure 6*: Experimental hardening plant (CAD model): 1- austenitizing furnace, 2- oil bath, 3- lead bath, 4- water bath, 5- robot handling systems*

The heat treatment of the wire, also known as hardening, takes place in two stages, the hardening of the material and the tempering which follows. A simplified view is that the hardening is dependent only on the austenitizing temperature and time and the oil hardening temperature and time (cf. Fig. 5). The tempering is, again, dependent on the temperature and time spent in the tempering medium which

is, in most cases, lead. As it is these six hardening and tempering parameters which set the strength of the wire and thus its capacity to be coiled etc., it will be necessary to determine the nominal values for tension and torsion in the material as soon as it has gone through these processing stages.
The next experimental step is a simulation of the tempering of the spring or component (spring tempering), carried out on the wire. A commercially available fan oven is used for this heat treatment. Again, the parameters for the tempering temperature and time are varied. Then tension and torsion nominal values are established for these samples, too. Comparing the samples made of hardened material with those made of hardened and then spring-tempered material makes it possible for statements on increase or decrease in the strength and shaping parameters caused by the heat treatment in the spring manufacturing stages. With the aim of achieving results that can be put to practical use in industry the parameters selected for the hardening and tempering were close to those already used by industry. Tempering times between 0.5 min and 5 min at tempering temperatures of 420 °C to 460 °C (for the wire manufacture) combined with spring tempering times between 15 min and 60 min and temperatures for spring tempering of 300 °C to 400 °C. The basic thinking behind the experiments was the need to find hardening parameters in both wire and spring manufacture that would lead to the best material properties in the finished spring. In relation to the wire from which the spring is to be made, first a low yield point should be set at the wire works in order to minimise the forces and wear on the coiling pins when the springs are being coiled. To produce the end product, i.e. a helical compression spring that will cope with demanding static, dynamic and/or thermal stress, the necessary high strength is developed after the spring coiling by targeted influencing of the $\tau_{t\ zul}$ during tempering of the spring in the spring works. The parameters of the wire production were comprehensively combined in the experimental plant presented with those of ensuing heat treatment of the springs. In tensile strength and torsional strength tests the properties of the wire were established. Simulating the spring tempering process on the wire and then determining the nominal strength values to be expected in the spring made from it also facilitates more precise dimensioning and manufacture of springs.

Figures 7 – 10 show the technical yield point under torsional stress $\tau_{t\,0,04}$ and the tensile strength R_m. These levels were determined from samples of 65SiCrV6 material of d = 4.5 mm which were austenitized at a temperature of 880°C for 2.5 min. For the tempering time and temperature, a number of variants were used. The Figures on the left (7 and 9) show the nominal values for the relevant samples immediately after hardening. The Figures on the right (8 and 10) show the same nominal value for samples which received spring tempering in addition. It can be clearly seen that the yield point under torsional stress $\tau_{t\,0,04}$ is considerably more influenced by the spring tempering (up to approx. 10 %) than is the tensile strength R_m (approx. 0 % to 2.5 %). The experiments also show that the increase in strength to be achieved by spring tempering is the higher, the lower the hardening temperature set previously during the wire manufacture [3].

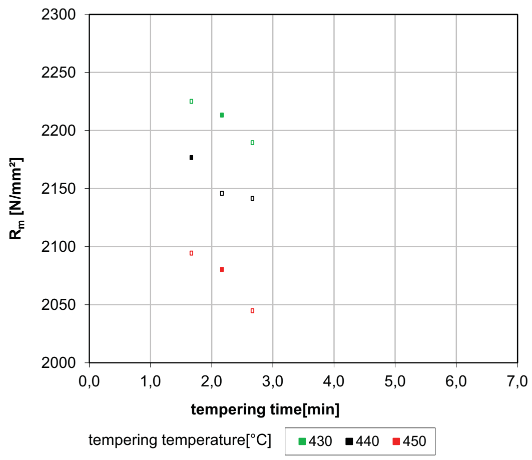


Figure 7: *Tensile strength R_m in relation to tempering regime, without spring tempering of the 65SiCrV6 wire, d = 4.5 mm*

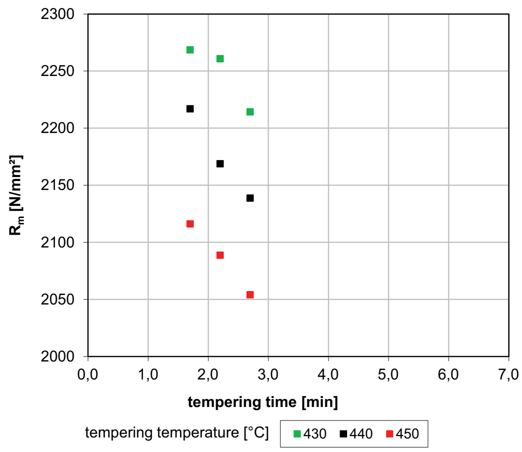


Figure 8: *Tensile strength R_m in relation to tempering regime, with spring tempering of the 65SiCrV6 wire, d = 4.5 mm*

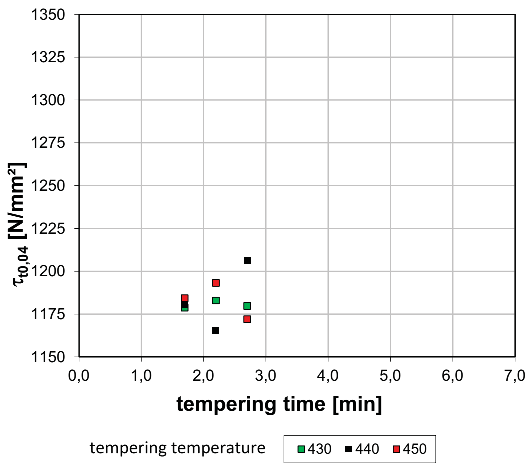


Figure 9: Technical yield point of torsional stress $\tau_{t\,0,04}$ in relation to tempering regime, without spring tempering of the 65SiCrV6 wire, d =4.5 mm

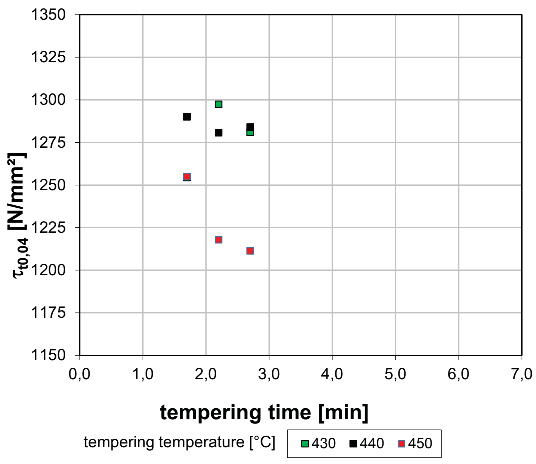


Figure 10: Technical yield point of torsional stress $\tau_{t\,0,04}$ in relation to tempering regime, with spring tempering of the 65SiCrV6 wire, d =4.5 mm

4. OPTIMISATION OF SPRING PROPERTIES

By means of about 5000 hardening experiments in the researchers' hardening and tempering plant it was possible to find two optimal parameter combinations for wire hardening and spring tempering. These experimental results were then computed to fit industrial wire manufacture using thermal substitution models and applied to passage tempered wires. This produced wire material with optimal strength properties (see Fig. 11 and 12), which it was possible to use for the production of experimental springs. The experimental springs were compared with versions produced identically from material that came from a non-optimised lot.

It is quite clear that springs made from material with an optimised yield point under torsional stress show significantly lower pre-setting values (Fig. 13). Furthermore, in the springs made of optimised wire longer life is achieved both in time and in fatigue strength (Fig. 14 and 15) [4].

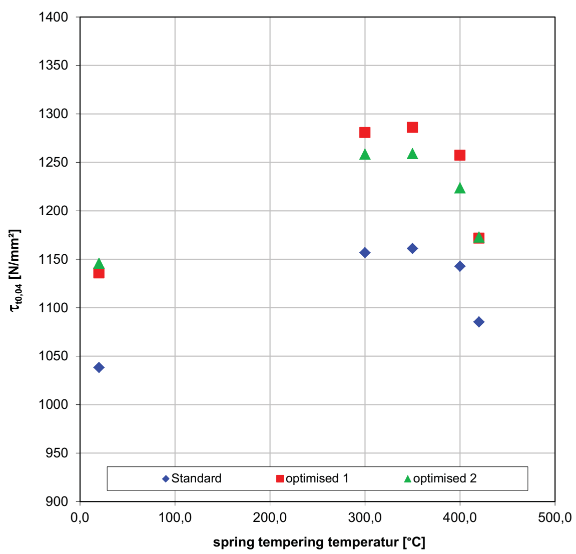


Figure 11:
Technical yield point under torsional stress $\tau_{t0,04}$ from spring tempering experiments on passage tempered wires of diameter d = 4.5 mm, material 65SiCrV6 SC

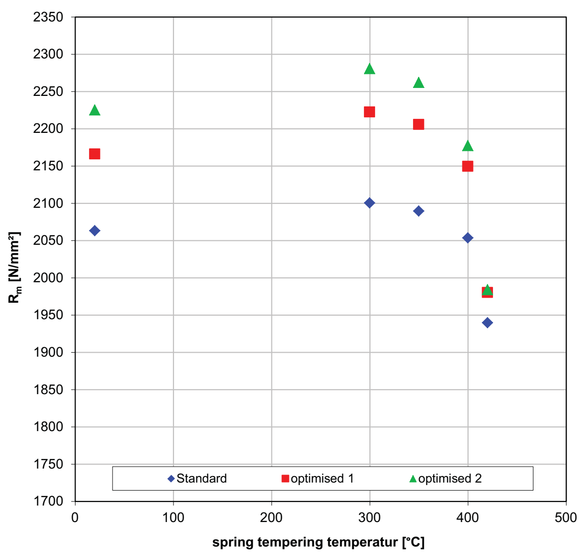
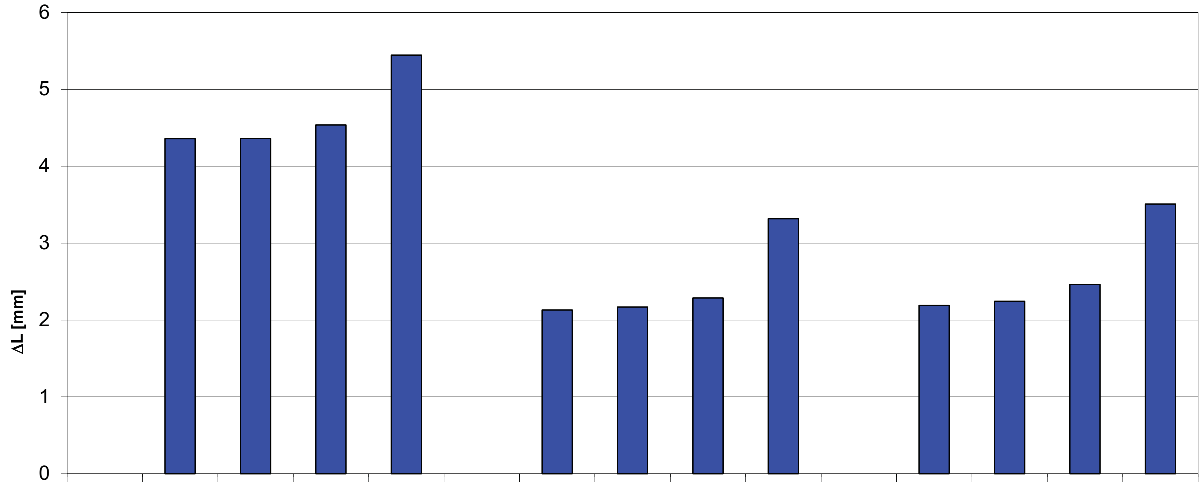


Figure 12:
Tensile strength R_m from spring tempering experiments on passage tempered wires of diameter d = 4.5 mm, material 65SiCrV6 SC



wire number	450924	450924	450924	450924	wire number	450925	450925	450925	450925	wire number	450926	450926	450926	450926
material	65SiCrV6 SC	65SiCrV6 SC	65SiCrV6 SC	65SiCrV6 SC	material	65SiCrV6 SC	65SiCrV6 SC	65SiCrV6 SC	65SiCrV6 SC	material	65SiCrV6 SC	65SiCrV6 SC	65SiCrV6 SC	65SiCrV6 SC
regime	standard	standard	standard	standard	regime	optimised 1	optimised 1	optimised 1	optimised 1	regime	optimised 2	optimised 2	optimised 2	optimised 2
spring temperig temperature [°C]	300	350	400	420	spring temperig temperature [°C]	300	350	400	420	spring temperig temperature [°C]	300	350	400	420
spring tempering time [min]	60	30	15	30	spring tempering time [min]	60	30	15	30	spring tempering time [min]	60	30	15	30

Figure 13: *Pre-setting values for springs made of 65SiCr V6 SC with* d *= 4.5 mm*

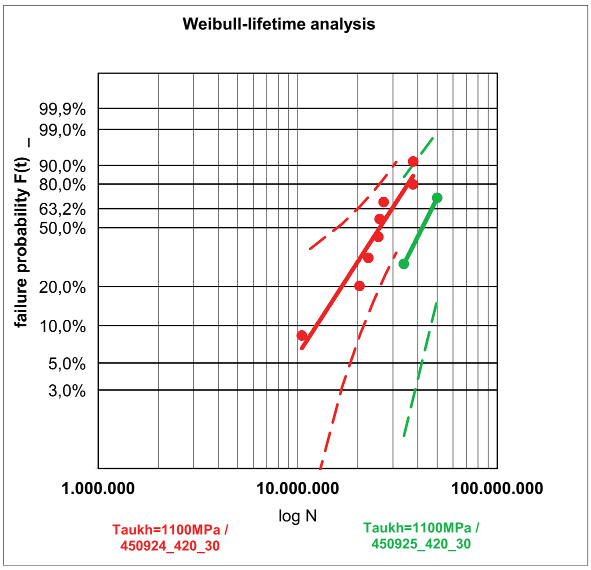


Figure 14: *Weibull lifetime analysis of springs tempered at 420 °C for 30 min made of 65SiCr V6 SC with a wire diameter of* d *= 4.5 mm. Red: normally hardened wire; green: optimised 1*

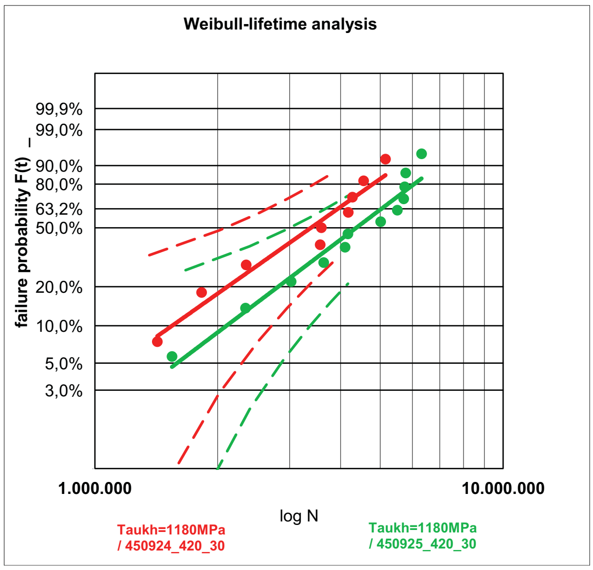


Figure 15: *Weibull lifetime analysis of springs tempered at 420 °C for 30 min made of 65SiCr V6 SC with a wire diameter of d = 4.5 mm. Red: normally hardened wire; green: optimised 1*

5. CONCLUSIONS

With the test stations available to the research group (developed by them) and the newly developed experimental hardening and tempering plant it has for the first time become possible to imitate in the laboratory all the heat treatment procedures from the wire works to the finished spring, using completely independent parameter variation, and then to compute the results. The research group is thus in a position to model the optimum finishing process for other wire products and provide industry with the results, all without high expenditure of time and money. In addition, conclusions can be drawn for the design of new passage tempering plant to be used in wire manufacturer.

The knowledge obtained to the effect that heat treatment processes calculated in combination for wire and spring manufacturer will enable shaping and strength properties to be specifically improved is promising for improved manufacture and more accurate dimensioning of high-capacity springs. It was proved that the hardening and tempering parameters have varying effects on yield points and ultimate tensile strength. The nominal value for the yield point under torsional stress which is particularly important for the materials used in helical compression springs can be increased by up to 10 % by optimal matching up of the wire hardening and component tempering parameters. It is fundamentally possible to achieve reduction of maximum strength of the material to improve capacity for coiling after the wire works and then to set the final strength value during the manufacture of the spring. The hardening regimes used currently in different wire works result in wide variation of the technical yield point under torsional stress $\tau_{t\ zul}$ while the tensile strength R_m is the same and this can result in turn in springs of different capacities and early failures in practical use. It is also clear that static and dynamic strength cannot be simultaneously optimised but that the heat treatment must be set at all stages to meet the use to which the spring is to be put.

6. ACKNOWLEDGMENT

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